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(54) ELECTROMAGNETIC TRANSDUCERS

(71) We, INTERNATIONAL BUSINESS MACHINES CORPORATION, a Corporation organized and existing under the laws of the State of New York in the United States of America, of Armonk, New York 10504, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to electromagnetic transducers of the kind having a conductive strip sandwiched between a first magnetisable member and a second substantially laminar magnetisable member of a magnetisable yoke. The yoke defines a transducing gap adjacent one edge of the strip and forms a path around the strip for magnetic flux.

Electromagnetic transducers may be employed in magnetic recording apparatus to write information on and to read information from a magnetisable record medium during relative motion between the transducer and the medium. Generally, such information is recorded in equidistant parallel or concentric tracks. The kind of transducer to which the invention relates is particularly suitable for production in miniaturised form because of its simple structure. Consequently, such transducers are useful in recording information at high surface densities where the tracks must be very narrow and closely spaced. Particularly at such high track densities, it has been found that when previously recorded data is overwritten, thermal effects or mechanical tolerances can result in a slight misregistration of the transducers with a previously recorded track. Consequently, parts of the old data may be unerased by the new. If, on a subsequent read operation, the transducer has returned to its position over the old data track, the unerased portions of the old data will be detected as noise.

Accordingly, the present invention provides an electromagnetic transducer for writing sig-

nals onto and reading signals from a magnetisable record medium during relative motion therebetween, the transducer having a conductive strip for connection in an external circuit and a magnetisable yoke comprising a first magnetisable member and a second substantially laminar magnetisable member between which the strip is sandwiched, the yoke defining a transducing gap adjacent one edge of the strip, the yoke members being magnetically joined at the other edge of the strip so that the yoke forms a path around the strip by way of which, in a reading operation, magnetic flux, resulting from a varying magnetic field incident on the gap, links the circuit to induce an electrical signal therein, the yoke having edge and centre portions which are so constructed that such electromagnetic induction of electrical signals in response to an incident magnetic field is relatively less efficient for fields incident on the gap edges than for fields incident on the gap centre.

The invention will now be described, by way of example only, with reference to preferred embodiments thereof as illustrated in the accompanying drawings, in which:—

Figure 1a is a plan view of one electromagnetic transducer according to the present invention;

Figure 1b is an end view of the transducer of Figure 1a;

Figure 1c is a cross sectional view taken on the line A—A of the transducer of Figure 1a;

Figure 2 shows a second electromagnetic transducer according to the present invention;

Figure 3a is a plan view of a third electromagnetic transducer according to the present invention;

Figure 3b is an end view of the transducer of Figure 3a;

Figure 4a is a plan view of a fourth electromagnetic transducer according to the present invention;

[Price 25p]

Figure 4b is a cross sectional view taken on the line A—A of the transducer of Figure 4a;

Figures 5a and 5b show test results from a transducer of the type shown in Figure 4;

Figure 6 shows a fifth electromagnetic transducer according to the present invention;

Figure 7a is a plan view of a sixth electromagnetic transducer according to the present invention; and

Figure 7b is a cross sectional view taken on the line A—A of the transducer of Figure 7a.

The electromagnetic transducers of Figures 1 to 4 and Figures 6 and 7 have several common features of construction and operation. Each includes a "single turn" copper strip element consisting of two spaced apart limbs connected at their ends by a bridging strip. The bridging strip is sandwiched between two laminar magnetisable members made of a magnetic alloy containing Nickel and Iron. These members form a magnetisable yoke and define a transducing gap adjacent one edge of the strip.

The transducers are made by layer deposition techniques on a substrate (not shown) such as glass. The magnetisable members are formed by electroplating and the copper strip element by evaporation. The shapes of the component layers are defined by photo-resist, mask exposure and etching techniques. It should be understood that the illustrated transducer structures are idealised and simplified for ease of explanation. In practice additional layers would be employed, for example, to aid the electroplating steps, for smoothing, or for insulation.

Each of the illustrated transducers is employed in a respective magnetic recording apparatus and is electrically connected in the apparatus by way of the strip element limbs. In operation, each transducer is located adjacent a magnetisable record medium and is effective to write information on or read information from the medium during relative motion between them. To write on the medium, a write current is passed through the strip element which generates a magnetic field around the bridging strip. This field magnetises the yoke so as to produce a magnetic field extending across the transducing gap. The gap field penetrates the adjacent record medium and magnetises it in accordance with the modulations of the write current.

In the reading operation, a magnetic field from a track on the medium is incident on the transducing gap of the transducer. This magnetic field produces a flux in the yoke which passes around the bridging strip to link the circuit in which the strip element is connected. As the magnetically recorded information changes, corresponding electro-motive

forces are induced in the strip which, in turn, produce electric currents in the strip element circuit.

The transducers of Figures 1 to 4 and Figures 6 and 7 are distinguished by having differently constructed yoke edge and centre portions as will now be described.

The electromagnetic transducer of Figures 1a, 1b and 1c includes a copper strip element 10 consisting of two spaced apart limbs 11 connected at their ends by a bridging strip 12. The bridging strip is sandwiched between two laminar magnetisable members 13 and 14 which together form a magnetisable yoke 15. The members 13 and 14 define a transducing gap 16 adjacent one edge of the strip 12 and are magnetically joined to form a flux closure region 17 adjacent the opposite edges of the strip. The yoke 15 has edge portions 18 and a centre portion 19 made of different magnetic materials. Both these magnetic materials have the low hysteresis properties and linear magnetisation curve generally desirable in a magnetic transducer. A linear magnetisation curve means that the permeability of the material is substantially constant under all conditions other than saturation. Centre portion 19 is made of a Nickel-Iron alloy of relatively high permeability whereas edge portions 18 are of a Nickel-Iron-Cobalt alloy of substantially lower permeability. It has been found possible to produce permeabilities differing by a factor of around 7 with these materials.

The behaviour of the transducer is modified by the different construction of the edge and centre portions of the yoke 15. Because the edge portions 18 of the yoke are of lower permeability than the centre portion 19, the reluctance of the flux path around the strip from the gap edges is higher than that from the gap centre. Consequently, a magnetic field incident on the gap edges is relatively less effective to produce a flux passing around strip 12 than is such a field incident on the gap centre. By choosing the permeabilities to be as different as possible, the signal contribution from the edge portions can be attenuated to such an extent that the transducer effectively reads only over the centre portion of the gap.

Despite the high reluctance of the edge portions, the transducer can be made to write over the whole width of its yoke. By using a write current considerably in excess of that needed for the high efficiency centre portion a sufficiently strong field can be produced at the edges to saturate the record medium.

The transducer is thus effective to write a relatively wide track but to read a relatively narrow one. Consequently, the transducer can avoid or at least reduce the effects of mis-registration with previously recorded data that were described above. Since the edge portions of the yoke are relatively ineffective to read

recorded data, any unerased old data on the fringes of a track will not contribute significantly to the signal.

The relative efficiency of the edge portions of the yoke could be further decreased by modifying the structure of Figure 1. The flux closure 17 could be restricted to the centre portion 19. Slots could be introduced between the edge portions 18 and 19 to prevent flux from the gap edges travelling diagonally across the yoke to pass around the centre portion. It should be remembered, however, that, with this particular transducer, the degree of edge inefficiency introduced into the reading operation has to be paid for by a corresponding degree of overdriving when writing. In fact, even the least degree of edge inefficiency will produce some beneficial effect as noise resulting from unerased old data on the fringe of a track will be attenuated proportionately.

Although in the transducer of Figure 1 both the magnetisable members 13 and 14 have different edge and centre portions, a useful effect can still be obtained if the overlying member 13 alone is modified.

An alternative way of producing edge inefficiency when reading is to employ a relatively high hysteresis material in the yoke edge portions. The permeability of such material is not substantially constant but varies considerably with the applied field. It is therefore possible to choose a material whose permeability, under the conditions of substantially zero applied field prevailing during a reading operation, is low relative to the constant permeability of the yoke centre portion. A greater difference in permeabilities, under zero applied field conditions, can be achieved in this way than can be achieved with the different linear magnetic materials described above.

Transducers employing high hysteresis edge portions must be driven to saturation in a writing operation if the edge portions are to record effectively. However, suitable control of the magnetic properties of the yoke edge and centre portions will ensure that no significant overdriving is needed to saturate the edges once the centre is saturated. The high remanence of the edge portions will lead to some erasure when the head is not being used for writing. However, such erasure is not very harmful and, at worst, leads to a slight reduction in subsequently detected signals.

Several other alternative ways of varying the reluctance of the flux paths around the strip are possible. One of these, which allows the same magnetic material to be used for the edge and centre portions, is to thicken the centre portion of the overlying magnetisable member. Another way, as illustrated in Figure 2, is to introduce diagonal slots 21 and 22 in edge portions 27 and 28 of the overlying magnetisable yoke member. These

slots interrupt the path of flux around the bridging strip so increasing the edge path reluctance.

The transducer of Figures 3a and 3b has a copper strip element 30 consisting of two limbs 31 joined at their ends by a bridging strip 32. The bridging strip is sandwiched between a magnetisable overlay member 33 and a magnetisable underlay member 34. These members are made of a Nickel-Iron alloy and together form a magnetisable yoke 35. The members 33 and 34 define a transducing gap at one edge of the strip 32 and are magnetically joined in a number of flux closures 37 at the opposite edge. The yoke 35 has edge portions 38 and a centre portion 39 which differ from each other in two respects. One is that the separation of the underlay 34 and overlay 33 is less in the edge portions than in the centre portion. The other is that the yoke and the sandwiched portion of bridging strip 12 are extended further back from the transducing gap in the edge portions than in the centre portion, i.e., what can be conveniently termed the "throat height" of the yoke is altered.

The reading efficiency of the yoke portions has been found to decrease with either increase in throat height or decrease in conductor thickness. In both cases the leakage of flux between the underlay 34 and overlay 33 is increased. Much of this leakage flux is dissipated in the production of eddy currents in the strip 32 which do not contribute to the signal. The major contribution to the detected signal is made by flux which passes right around the yoke through the flux closures 37 although it is believed that a significant contribution is also made by that part of the leakage flux which leaks through the strip in the neighbourhood of the flux closures.

Although the writing efficiency of the yoke has been found to decrease with increased throat height, it has been found experimentally to increase with decrease in conductor thickness. Thus in the transducer of Figure 3, reading efficiency is decreased by both modifications of the edge portions 38 and the transducer is effective to read only over the centre portion 39. However, the decrease in writing efficiency with the increased throat height of the edge portions is offset by the reduced conductor thickness. So, in contrast to the device of Figure 1, the transducer of Figure 3 will write across substantially the whole width of its yoke without having to be overdriven. Like the transducer of Figure 1, the transducer of Figure 3 can be employed to write wide and read narrow in a magnetic recording apparatus so as to reduce the effect of transducer/track misregistration.

The transducer of Figures 4a and 4b has a conductive strip element 40 including limbs 41 and bridging strip 42. Strip 42 is sandwiched between a magnetisable overlay

member 43 and underlay member 44 which together form a yoke 45. The yoke defines a transducing gap along the lower edge of the bridging strip. A flux closure 47 is located beyond the opposite edge of strip 42 and extends along the length of a centre portion 48 of the yoke. This centre portion 48 is partially separated from edge portions 49 by slots 50 in the overlay member 43. These slots extend part way towards but terminate short of the transducing gap. The yoke edge portions 49 protrude beyond the ends of the bridging strip 42 where they are magnetically joined in edge flux closures 51. The protruding edge portions form a shunt path around the strip for magnetic flux.

Flux produced in the edge portions 49 of the yoke by a magnetic field incident on the gap edges tends to be shunted around the ends of the strip 42. Such flux does not link the circuit and so does not contribute to the detected signal. Flux originating the gap edges can contribute to the signal by passing diagonally to the centre portion 48 and around the flux closure 47 but this flux path is interrupted by the slots 50. Both the edge shunts 51 and the slots 50 thus act to reduce the reading efficiency of edge portions 49.

These factors also reduce the writing efficiency of the edge portions and it is necessary to overdrive the transducer to produce a strong enough write field at the edges. The transducer will not write over the whole length of the gap but is effective to write a track which is wider than the yoke centre portion.

The transducer of Figure 4 can thus be employed to write wide and read narrow so as to reduce the effect of transducer displacement.

The side flux closures 51 play the major part in introducing reading inefficiency in the edge portions of this device and the slots 50 could be omitted. In this case the difference in efficiencies between the edge and centre portions would be reduced. In contrast, if it were desired to increase the difference, slots similar to slots 50 could be introduced in the underlay member 44.

A typical set of test results for a device of the type shown in Figure 4 is given in Figures 5a and 5b. The device tested had a total gap length between the flux closures 51 of 15 mil. The length of the flux closure 47 was 5 mil.

Figure 5a shows the variation of the total transducer output with off-centre displacement of the transducer for a track written with a write current of 1 amp. The length of the plateau portion of the curve indicates the amount of displacement that can be tolerated. Letting the written track width be d_w and the read track width be d_r , the length of the plateau will give $\frac{1}{2}(d_w - d_r)$. Making the assumption that the detected signal will

have fallen by 50% when the head is displaced by $d_w/2$ thus permits d_w and d_r to be calculated. It should be noted that the level plateau and the sharp discontinuity between plateau and sloping portion of the curve indicates good write wide and read narrow characteristics. If there were no edge inefficiency a uniformly sloping line would be expected. If there were only a small degree of inefficiency the transition between plateau and slope would be more rounded.

Figure 5b shows the variation of d_w and d_r with write current, individual values having been obtained from cures such as Figure 5a. The maximum written track width is achieved at write currents of around 900mA. It is believed that this width (11 mils) is less than the total gap length because of shunting of write flux by the edge closures. It can be seen that an offcentre displacement of about 2 mils can be tolerated before noise from a previously recorded track becomes a problem.

The transducer shown in Figure 6 bears some resemblance to that of Figure 4 with the difference that there is no side flux closure. The transducer comprises a strip element 60 having limbs 61 and a bridging strip 62 which is sandwiched between a magnetisable overlay 63 and an underlay of a yoke 65. The yoke defines a transducing gap along the lower edge of strip 62 and has a flux closure 67 along a portion of the opposite edge. The flux closure defines a centre portion 68 of the yoke which is partially separated from edge portions 69 by slots 70 in the overlay member 63. These slots extend part way towards but terminate short of the transducing gap. The edge portions 69 of the yoke terminate short of the ends of the bridging strip 62 at points approximately half way across the width of their respective limbs.

It has been found by experiment that the edge portions 69 are relatively inefficient for both reading and writing. Thus, as with the transducer of Figure 4, this transducer reads over a narrower region than it writes if it is suitably overdriven when writing. The cause of the edge inefficiency is not as clearly identifiable as with the transducers of Figures 1 to 4. It is believed that some flux in the edge portions 69 will penetrate the conductor and be dissipated as eddy currents. Further, the path of flux from the edges to the flux closure 67 is interrupted by the slots 70. Experimental results comparable with those of Figure 5 have been achieved for devices of the type shown in Figure 6. Extension of the edge portions 69 further towards the ends of bridging strip 62 did not remove the effect but produced a rounding of the curve equivalent to that of Figure 5a. This is believed to be a result of the more gradual tapering off of the write field in this modified form of transducer than in the devices of

Figures 4 or 6 both of which appear to produce a sharply defined written track.

The transducer of Figure 7 introduces reading edge inefficiency by yet another means. As in the transducers already described, the device of Figure 7 includes a strip element 80 having limbs 81 and a bridging strip 82, the latter being sandwiched between a magnetisable overlay member 83 and an underlay member 84 with together form a yoke 85. The yoke defines a transducing gap 86 along one edge of the strip 82 and a centre portion 88 of the yoke is flux closed beyond the opposite edge of strip 82 in a closure 87. Edge portions 89 of the yoke are also flux closed in closures 90 through holes 91 in the bridging strip 82. There is no functional significance in the fact that underlay member 84 extends beyond flux closure 90 in edge portion 89. This is simply a feature of construction.

In a reading operation, flux produced by the magnetic field incident on the gap edges passes round the yoke via flux closures 90. As the closures 90 are completely surrounded by conductor, flux passing through them simply induces an eddy current and does not contribute to the signal at all. Thus the edge portions are virtually ineffective for reading purposes. In writing operation, the edge portions 89 have been found to be almost as efficient as the centre portion 88. The effect of the current passing above holes 91 appears to be offset by the reduced throat height of the yoke in the edge portions. Only a small degree of overdriving is necessary when writing.

Because of this difference in construction of the edge and centre portions of the yoke, the transducer of Figure 7 can be employed to write a wide track and to read only over a comparatively narrow portion of this track thereby to overcome the effects of misregistration of the transducer.

The transducers of Figures 1 to 4 and of Figures 6 and 7 were all said to be made by layer deposition on a substrate such as glass. It is not essential that this precise construction be adopted. In those cases where no modification of the magnetisable underlay is necessary, a magnetisable ferrite block can be used as both underlay and substrate. Nor is it essential that the transducer be an integrated structure built up of layers. Discrete components could be employed and bonded together. Where discrete components are used and the structure permits, the various flux closures could be replaced by a relatively large overlap of the magnetisable yoke members, spaced by the thickness of the conductor.

The illustrated transducers all have only a single turn strip element. It would be possible, at least in the case of the transducers of Figures 1, 2 and 4 to employ a multiple turn

element such as a flat spiral strip. Electrical insulation of the strip from the yoke would then be particularly necessary.

WHAT WE CLAIM IS:—

1. An electromagnetic transducer for writing signals onto and reading signals from a magnetisable record medium during relative motion therebetween, the transducer having a conductive strip for connection in an external circuit and a magnetisable yoke comprising a first magnetisable member and a second substantially laminar magnetisable member between which the strip is sandwiched, the yoke defining a transducing gap adjacent one edge of the strip, the yoke members being magnetically joined at the other edge of the strip so that the yoke forms a path around the strip by way of which, in a reading operation, magnetic flux, resulting from a varying magnetic field incident on the gap, links the circuit to induce an electrical signal therein, the yoke having edge and centre portions which are so constructed that such electromagnetic induction of electrical signals in response to an incident magnetic field is relatively less efficient for fields incident on the gap edges than for fields incident on the gap centre.

2. A transducer as claimed in claim 1 in which the conductive strip forms part of a conductive strip element, which element includes two spaced apart limbs connected at their ends by the conductive strip.

3. A transducer as claimed in claim 1 or claim 2 in which the edge portions and the centre portion form respectively relatively high and relatively low reluctance paths around the strip to link the circuit.

4. A transducer as claimed in claim 3 in which the magnetic material of the second magnetisable member is of lower permeability in the edge portions than in the centre portions of the yoke thereby producing said difference in path reluctance.

5. A transducer as claimed in claim 3 in which the thickness of the second magnetisable member is greater in the centre portion of the yoke than the edge portions thereby producing said difference in path reluctance.

6. A transducer as claimed in claim 3 in which slots in the second magnetisable member interrupt the flux path from the gap edges around the strip thereby producing said difference in path reluctance.

7. A transducer as claimed in claim 4 in which the first magnetisable member is also laminar, the magnetic material of the first magnetisable member also being of lower permeability in the edge portions than in the centre portion of the yoke.

8. An electromagnetic transducer substantially as hereinbefore described with reference to and as illustrated in Figures 1a, 1b and 1c of the accompanying drawings.

9. An electromagnetic transducer substan-

tially as hereinbefore described with reference to and as illustrated in Figure 2 of the accompanying drawings.

- 5 10. A transducer as claimed in either claim 1 or claim 2 in which the edge portions are adapted to produce a greater leakage of flux through the strip between the first and second magnetisable members than is the centre portion.
- 10 11. A transducer as claimed in claim 10 in which the strip and the yoke are extended further back from the transducing gap in the edge portions than in the centre portions.
- 15 12. A transducer as claimed in claim 10 or claim 11 in which the first and second magnetisable members are closer together in the edge portions than in the centre portion of the yoke.
- 20 13. A transducer as claimed in claim 12 as dependent on claim 11 in which the first and second magnetisable members are magnetically joined on the opposite side of the strip from the transducing gap along both the edge portions and the centre portion of the yoke.
- 25 14. An electromagnetic transducer substantially as hereinbefore described with reference to and as illustrated in Figures 3a and 3b of the accompanying drawings.
- 30 15. A transducer as claimed in either claim 1 or claim 2 in which the yoke edge portions extend longitudinally of the gap and protrude beyond the conductive strip to form a shunt path therearound.
- 35 16. A transducer as claimed in claim 15 in which each edge portion of the yoke is partially separated from the centre portion by a slot in the laminar magnetisable member which terminates short of the transducing gap.
- 40 17. A transducer as claimed in claim 15 or claim 16 in which those parts of the magnetisable members forming the centre portion of the yoke are joined magnetically on the opposite side of the strip to the transducing gap.
- 45 18. A transducer as claimed in any of

claims 15 to 17 in which the magnetisable members are magnetically joined where they protrude beyond the strip.

- 50 19. An electromagnetic transducer substantially as hereinbefore described with reference to and as illustrated in Figures 4a and 4b of the accompanying drawings.

- 55 20. A transducer as claimed in claim 2 in which yoke edge portions extend longitudinally of the transducing gap, each edge portion being partially separated from the centre portion by a slot in the second magnetisable member which terminates short of the transducing gap.

- 60 21. A transducer as claimed in claim 20 in which the second magnetisable member extends approximately half way across the width of each limb to define the yoke edge portions.

- 65 22. A transducer as claimed in claim 20 or claim 21 in which those parts of the magnetisable members forming the yoke centre portion are joined magnetically on the opposite side of the conductive strip to the transducing gap.

- 70 23. An electromagnetic transducer substantially as hereinbefore described with reference to and as illustrated in Figure 6 of the accompanying drawings.

- 75 24. A transducer as claimed in claim 1 or claim 2 in which those parts of the magnetisable members forming the centre portion of the yoke are magnetically joined on the opposite side of the conductive strip to the transducing gap and in which those parts of the magnetisable members forming the edge portions of the yoke are magnetically joined through respective holes in the conductive strip.

- 80 25. An electromagnetic transducer substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

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Chartered Patent Agent,
Agent for the Applicants.

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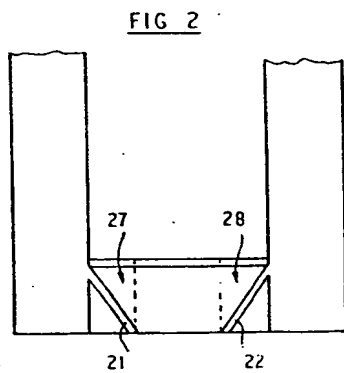
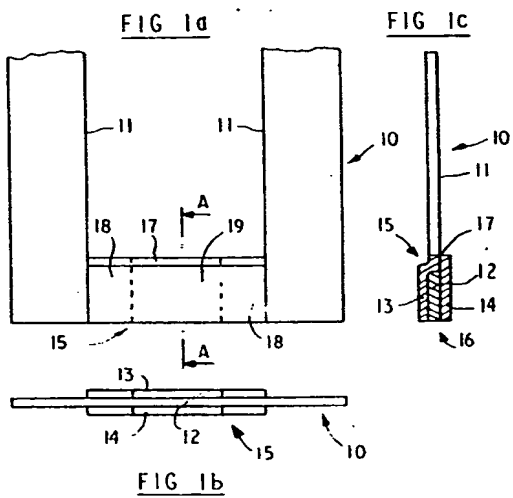
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Sheet 2

FIG 3a

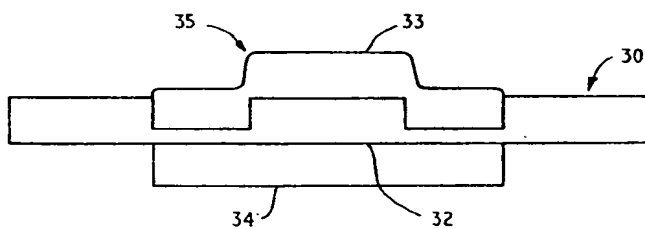
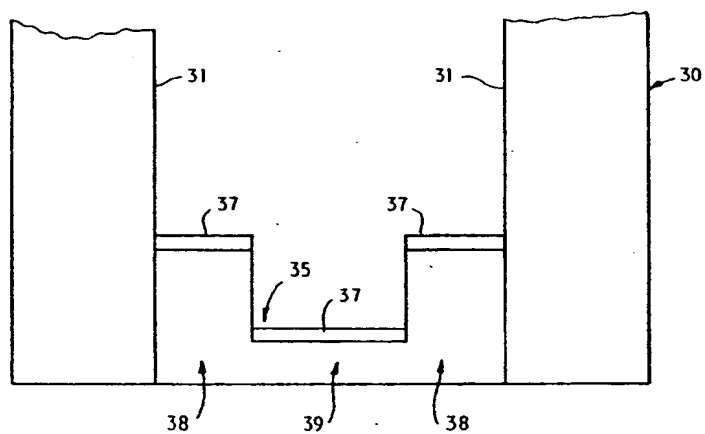


FIG 3b

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Sheet 3

FIG 4a

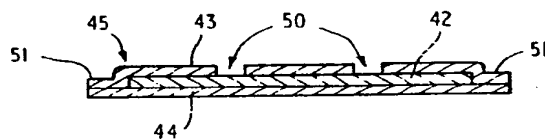
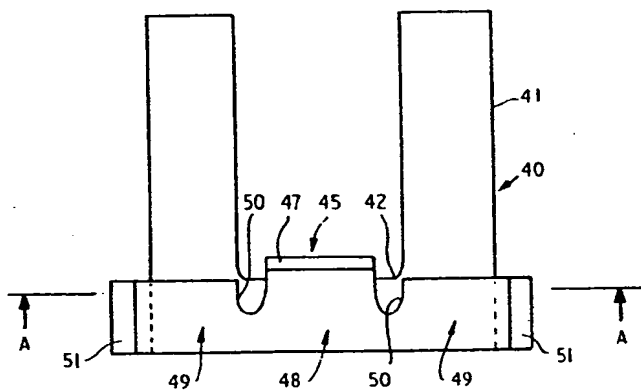


FIG 4b

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Sheet 4

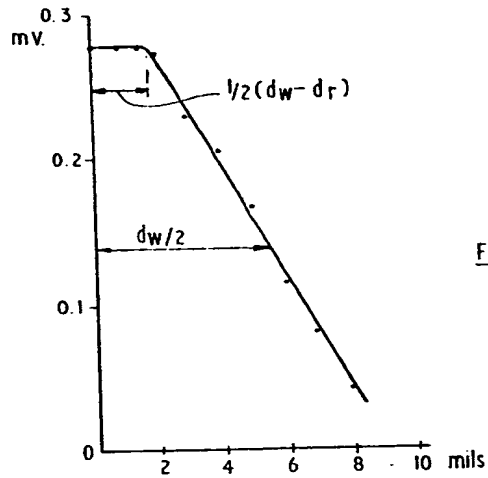


FIG 5a

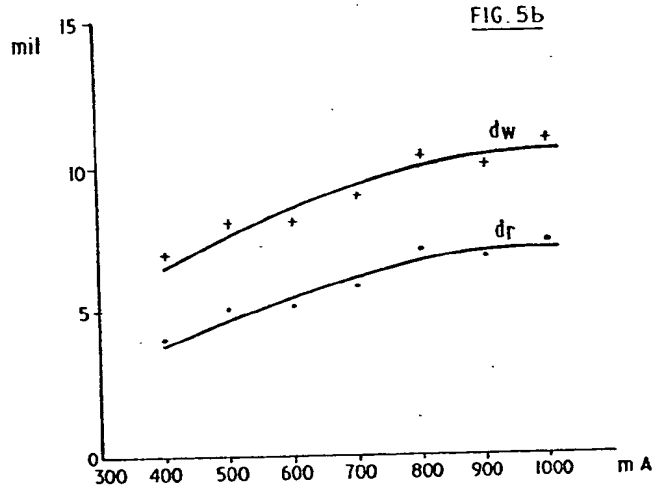


FIG 5b

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Sheet 5

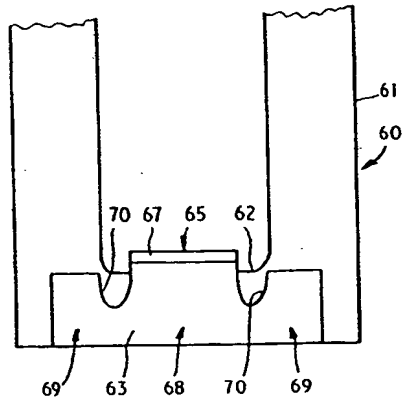


FIG 6

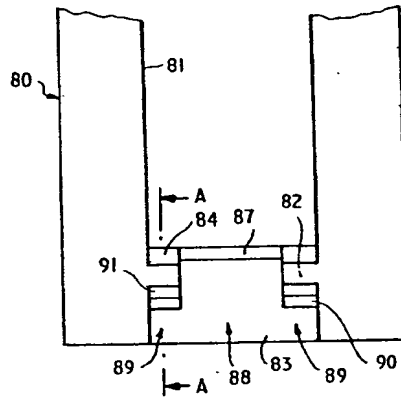


FIG 7a

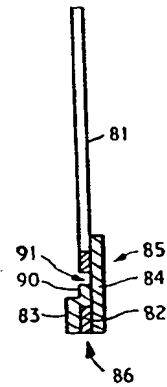


FIG 7b